EXPERIMENTAL INVESTIGATION OF THE EFFECT OF THE USE OF NANOPARTICLE ADDITIONAL BIODIESEL ON FUEL CONSUMPTION AND EXHAUST EMISSIONS IN TRACTOR USING A COATED ENGINE

by

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This study focuses on reducing the fuel consumption and exhaust gas emission values of the tractor used in the agricultural field. With the additive added to the fuel and the coating of the tractor engine, the fuel consumption values were reduced, and agricultural production costs were tried to be reduced. On the other hand, exhaust emission values were also tried to be reduced and thus a more environmentally friendly production method was aimed to be adopted. For this reason, the cylinders of the tractor engine were coated with Al_2O_3 + 13%TiO_2 metal powders mixed by mass using the plasma spray method. All experiments were repeated by attaching these coated pistons to the engine. The fuel used in the experiments was purchased from a commercial company and the nanoparticle (molybdenum) additive was added to the biodiesel at the rates of 25 ppm, 50 ppm, 100 ppm, and 200 ppm by mass. The fuel mixtures obtained in the coated and uncoated engine, when the engine is in the full throttle position, using the PTO load test unit at 1000 rpm, 1200 rpm, 1400 rpm, 1600 rpm, 1800 rpm, and 2000 rpm. It has been tested by loading at 2200 rpm, 2400 rpm, and 2600 rpm engine speeds. Code for the Official Testing of Agricultural and Forestry Tractor Performance standards were adhered to during all engine tests. The results showed that coating the cylinders and adding nanoparticles into biodiesel reduces the fuel consumption value, increases the exhaust gas temperature, decreases HC, CO, and PM emissions, and increases NO_x emissions.

Key words: *agricultural mechanization, tractor, coating, biodiesel, nanoparticle*

Introduction

With the mechanization required for agricultural production, the workload is reduced, and agricultural production yields are increased. For this reason, fuel consumption values in agricultural production are seen as an important input that affects the costs of agricultural products. The efficiency of agricultural vehicles and reducing fuel consumption costs are as important as mechanization in agricultural production.

Tractors are one of the most important tools used in agricultural production. An internal combustion engine drives the tractor. Tractors transmit the power they produce in the internal combustion engine to the wheels, tail, and head shafts thanks to the power transmis-

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sion organs. They also enable the agricultural machinery mounted on them to move. Many tractors with internal combustion engines with various power generation capacities are preferred in agricultural production in Turkey. Reducing the exhaust emissions from the tractors also has the potential to cause the accumulation of heavy metals in agricultural products produced with the pollution rate of the fields [1, 2].

Researchers report that in their studies on internal combustion engines, the coating of the engines increases the combustion efficiency and thus reduces exhaust emissions [3-9]. In these studies, it is reported that coating processes are also effective in the life of the engines.

As it is known, polluting gases from vehicles exhaust emissions pollute nature more and more every day. Researchers talk about the importance of using biomass fuels instead of petroleum-based fuels to eliminate these situations. The biomass fuels used reduce exhaust emissions and ensure that more environmentally friendly fuels are consumed. Prevention measures to reduce global warming are becoming increasingly difficult due to the agreements and obligations signed by the countries. In this case, the only solution to reduce the emission values in return for the agreements is shown as liquid biomass fuels, which will take the largest share among renewable energy sources. Especially biodiesel, which is one of them, is highly preferred because it can be produced from waste oils and vegetable sources [10, 11]. In studies on the use of biodiesel, it is reported that biodiesel increases fuel consumption and NO_x value, and reduces CO, HC, and PM emissions due to its low calorific value, high density, and viscosity value [12-18].

Another research area that researchers focus on to reduce exhaust emissions is mixing nanoparticles into fuels. It is reported that nanoparticles used as additives reduce fuel consumption and exhaust emissions [19-25].

In this study, the pistons of the internal combustion engine of the tractor, which is used as a labor force in agricultural production, were coated with Al_2O_3 + 13%TiO_2 metal powders using the plasma spray method. Molybdenum was added as an additive to the biodiesel fuel, which will be used as the experimental fuel, at the rates of 25 ppm, 50 ppm, 100 ppm, and 200 ppm as nanoparticles. The obtained fuel mixtures are used in the uncoated and coated engine using the loading unit connected to the PTO at full throttle position at 1000 rpm, 1200 rpm, 1400 rpm, 1600 rpm, 1800 rpm, 2000 rpm, and 2200 rpm. It has been tested at engine speeds of 2400 rpm and 2600 rpm. The changes in fuel consumption value, exhaust gas temperature value and exhaust emission values at all engine speeds were recorded and the results were graphed, and the findings were explained in the following sections.

Method

The biodiesel used in the experiments was obtained from a commercial production company. The technical properties of biodiesel are given in tab. 1.

The pistons of the engine are coated with Al_2O_3 + 13%TiO_2. All four pistons of the engine purchased for this purpose were made by the plasma spray method in the company that does this job commercially. The engine tests were repeated with the same fuel types in cases where the engine was coated and uncoated. The nanoparticle material mixed into the experimental fuels was obtained from a commercial company. The technical properties of the nanoparticle (molybdenum) used are given in tab. 2.

The nanoparticle additive was added to biodiesel in the form of 25 ppm, 50 ppm, 100 ppm, and 200 ppm. Each fuel mixture was subjected to a mixing frequency of 50 Hz for two hours in ultrasonic mixers. The resulting mixtures were used directly in the engine without creating precipitation. From the abbreviations given in the table, B refers to 100% biodiesel,

Table 1. Technical characteristics of biodiesel

Characteristic	Biodiesel
Formula	$C_{19}H35$, 202
Molecular mass [$gmol^{-1}$]	296
Lower calorific value [$kJkg^{-1}$]	37100
Density, 15 °C, [gL^{-1}]	895
Kinematic viscosity, 40 °C, [mm^2s^{-1}]	4.3
Cetane number	57
Flash point [^{C}]	112

Table 2. Properties of molybdenum [26]

Purity	99.95%
Particle size	44 microns
CAS	7439-98-7
Melting point	2610 °C
Boiling point	5560 °C
Crystal structure	Cubic, body-centred
Density	8.2 g/cm^3
Form structure	Powder

BM25; 100% biodiesel + 25 ppm molybdenum mixture, BM50; 100% biodiesel + 50 ppm molybdenum, BM100; 100% biodiesel + 100 ppm molybdenum mixtures created by adding BM200; 100% biodiesel + 200 ppm molybdenum. In addition, the data in the experiments with coated are shown on the graph as CB, CBM25, CBM50, CBM100, and CBM200. Some physical and chemical properties of the new mixtures created are given in tab. 3.

Table 3. Physical and chemical properties of test fuels

	Fuel mixture				
Characteristic	B	BM25	BM50	BM100	BM200
Density, 15 °C, [gL^{-1}]	895	899	905	914	922
Kinematic viscosity, 40 °C, [mm^2s^{-1}]	4.7	4.7	4.8	5	5.1
Lower calorific value [$kJkg^{-1}$]	37100	37125	37225	37500	37926

Engine tests were carried out in the experimental set-up, whose schematic image is given in fig. 1. The exhaust gas temperature of the engine was measured with a *K*-type thermocouple. The fuel consumption value was determined with a precision scale.

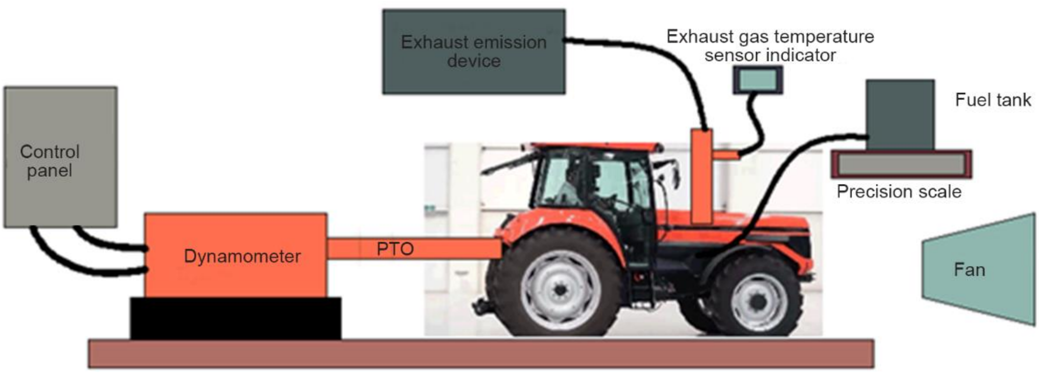

Figure 1. Schematic picture of the experimental set-up

The loading process of the engine was done with the PTO test unit. All engine tests were conducted by the OECD Standard Code for the Official Testing of Agricultural and Forestry Tractor Performance. During the experiments, the PTO speed of the tractor was set to 540 rpm. Afterwards, the engine is brought to the full throttle position and the operating speed of the engine is 1000 rpm, 1200 rpm, 1400 rpm, 1600 rpm, 1800 rpm, 2000 rpm, 2200 rpm, and 2400 rpm from the PTO shaft loading unit. During each loading process, engine exhaust gas temperature, fuel consumption values and exhaust emission values were measured and recorded. All procedures were repeated three times and the averages of the obtained data were taken.

Exhaust emission measurements were made with a Capelec CAP3201 brand emission device. Technical specifications of the exhaust emission device are given in tab. 4.

Table 4. Technical specifications of exhaust emission device

Brand and model	Capelec CAP 3201-4	Brand and model	Capelec CAP 3201-4
Preheat time	Minimum 1 minute	CO_2 (sensitivity (0.1%)	0-20 vol. %
Pump capacity	6 Lpm	O_2 (accuracy 0.01%)	0-21,7 vol. %
Operating temperature	–10 °C to +55 °C	NO_x (sensitivity 1 ppm)	30-10000 ppm
Moisture	30-90%	Oil temperature	5 ^{0}C-150 ^{0}C
Storage temperature	–32 °C to +55 °C	Lambda (air/fuel ratio coefficient)	0.8-1.2
HC (sensitivity 1 ppm)	0-20000 ppm	PM (accuracy 0.01%)	0-9.99 m^{-1}
CO (accuracy 0.001%)	0-5 vol.%		

Table 5. Technical specifications of tractor engine

Characteristic	
Maximum engine power	75 hp
Number of cylinders	4
Air intake system	Turbo intercooler
Engine capacity	3.9 L
Maximum torque	2981400 minimum
Transmission	8 forward + 2 reverses
Dry spindle cycle	540 rpm at 1967 rpm
Fuel type	Diesel
Fuel system	Direct injection

The tractor used during the experiments is already used by many farmers in Turkey. Information on the internal combustion engine of the tractor is given in tab. 5.

Results and discussion

In fig. 2, the variation of the specific fuel consumption (SFC) value in coated and uncoated engines according to engine speed and fuel type is given. In internal combustion engines, the data obtained after measuring the fuel consumption value by mass or volume are used to calculate the SFC. The SFC refers to the amount of fuel that must be consumed to produce one kW of work [27]. With the addition of nanoparticles into biodiesel fuel, SFC showed a tendency to decrease at all engine loads, fuel mixtures and coated engines. This shows that the addition of nanoparticles increases the combustion efficiency. Studies have reported that micro-explosions occur in fuels with the addition of nanoparticles. The resulting micro-explosions cause better mixing of the fuel mixtures taken into the cylinder and increase the combustion performance. In this study, the addition of nanoparticles into biodiesel provided positive results in terms of SFC. On the other hand, the SFC value has been further reduced with the coated engine. Coated engines prevent the heat in the pistons from turning into cooling water and useless work by radiation. In this way, more useful work can be obtained from the fuels taken in the cylinders. This provides both an increase in performance and a decrease in the SFC value. The results of the study are like other studies in the literature. In terms of SFC ratio, the highest decrease was obtained in the CBM200 fuel mixture in the coated engine at an engine speed of 12.4% at 1600 rpm, while the lowest reduction was obtained in the BM25 fuel mixture with 0.5% in the uncoated engine.

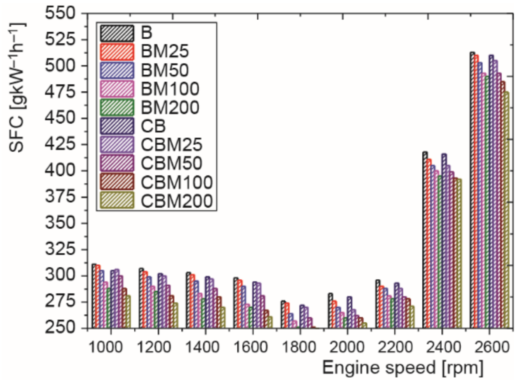

Figure 2. Change of the SFC value

In fig. 3, the variation of the exhaust gas temperature value in coated and uncoated engines according to engine speed and fuel type is given. In internal combustion engines, the exhaust gas temperature is expressed as an indicator of the combustion in the cylinder [28]. With the addition of nanoparticles to biodiesel, the exhaust gas temperature value increased in all fuel mixtures and engine loads. It is possible to explain this situation with the micro-explosion feature of the nanoparticle, increasing the cetane number and heating value. On the other hand, the oxygen in biodiesel can partially affect combustion efficiency. It is known that oxygen-rich fuels cause more fuel oxidation in the cylinder and thus increase the exhaust gas temperature. In addition, the exhaust gas temperature value increases even more with the use of fuel mixtures in the coated engine. In the coated pistons, the thermal conductivity coefficient decreased, and the heat obtained in the cylinder was trapped and turned into useful work, and the rest was removed as heat from the exhaust. The highest temperature value was obtained with the BM200 fuel mixture in the coated engine at 568 °C. In addition, the highest rate of increase was achieved with the use of BM200 fuel mixture in the coated engine with a rate of 13.9% at 1600 rpm.

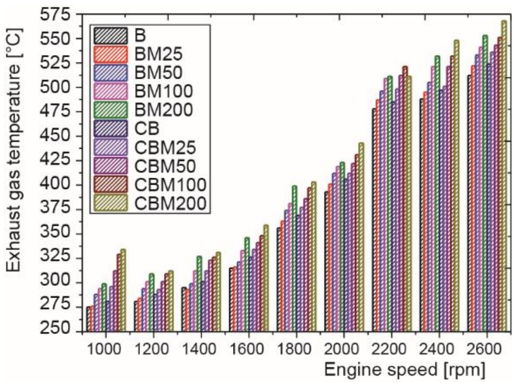

Figure 3. Variation of exhaust gas temperature

In fig. 4, the variation of CO value in coated and uncoated engines according to engine speed and fuel type is given. The CO emissions are generated by the removal of unburned fuels from the exhaust in internal combustion engines. The CO emissions may occur due to the partial combustion of the fuels taken into the cylinder in oxygen-free areas and the partial extinction of the cold fuels hitting the cylinder walls. With the addition of nanoparticles into biodiesel fuel, CO emissions tended to decrease at all engine loads and fuel mixing ratios. It is possible to explain this situation by the fact that the addition of nanoparticles increases combustion efficiency. It is thought that the increased heating value and micro-explosion with the addition of nanoparticles are effective in reducing CO emissions by partially improving combustion in the cylinder. On the other hand, with the use of fuel mixtures in the coated engine, the decrease in CO emissions continues to increase. In terms of CO emis-

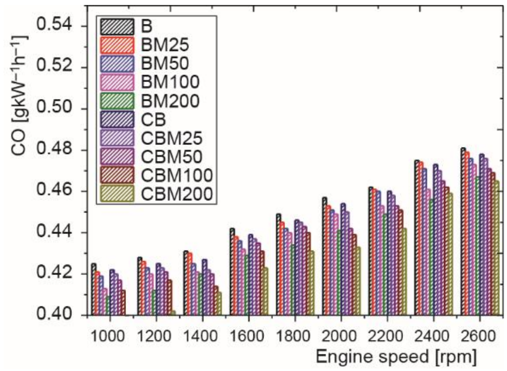

Figure 4. Change of CO emission value

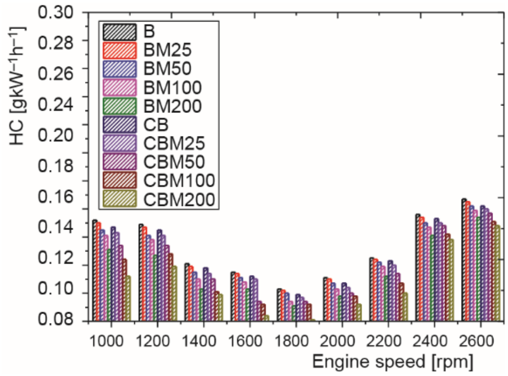

Figure 5. Change of HC emission value

sions, the highest amount of reduction was obtained with the CBM200 fuel mixture ratio of 6.8% at an engine speed of 1400 rpm, while the lowest amount of reduction was measured with the use of BM25 fuel mixture in an uncoated engine at an engine speed of 2400 rpm.

In fig. 5, the variation of HC emission value in coated and uncoated engines according to engine speed and fuel type is given. The HC emissions in internal combustion engines refer to the removal of unburned fuels from the exhaust. It is known that HC emissions occur because of the incomplete combustion of the fuels taken into the cylinder in Diesel engines from time to time due to a lack of oxygen in the cylinder. With the addition of nanoparticles to the biodiesel fuel, it is observed that while it tends to decrease at 1000 rpm, 1200 rpm, 1400 rpm, and 1800 rpm engine loads in coated and uncoated engines, it increases with the increase of engine speed at 2000 rpm, 2200 rpm, and 2400 rpm engine loads. At engine speed with maximum engine torque, HC emissions are at their lowest stage. In this case, it is an indication that all the fuel taken in the cylinder is converted into useful work by burning. With the increase in engine speed, the fuel/air mixtures taken into the cylinder did not mix completely and the combustion efficiency decreased. In this case, HC emissions increased. With the addition of nanoparticles into biodiesel, HC emissions tended to decrease at all engine loads. It is possible to explain this situation with the increase in thermal value and micro-explosion feature of nanoparticles. In this case, it is thought that nanoparticles added to biodiesel partially improve combustion and reduce HC emissions. The lowest HC emission was measured as 0.081 g/kWh with the use of CBM200 fuel mixture in the coated engine at an engine speed of 1800 rpm. The highest reduction amount was obtained with the CBM200 fuel mixture at 1800 rpm in the coated engine with a rate of 69.2%.

In fig. 6, the variation of NO_x emission values in coated and uncoated engines according to engine speed and fuel type is given. The NO_x emissions occur with the combustion of nitrogen gas in the air at high temperatures. The NO_x emissions are unwanted emissions. It is known that NO_x emissions increase in oxygen-rich biodiesel fuels. With the addition of nanoparticles to biodiesel fuel, NO_x emissions increase at all engine loads. This situation increases the tendency to increase with the increase of engine speed. The increase in engine speed in Diesel engines is possible with an increase in the amount of fuel taken into the cylinder. With the increase of the fuel taken into the cylinder, the temperature of the end of combustion increases, which causes an increase in NO_x emissions. With the addition of nanoparticles to biodiesel fuel, an increase in NO_x emissions is observed at all engine speeds and fuel mixtures.

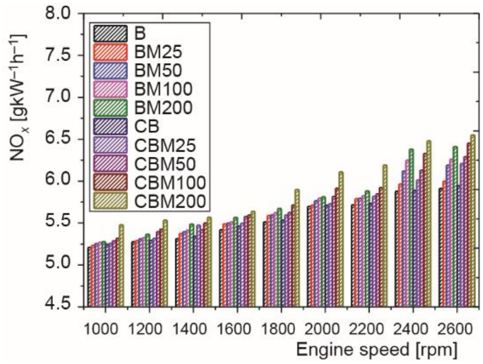

Figure 6. Change of NO$_x$ emission value

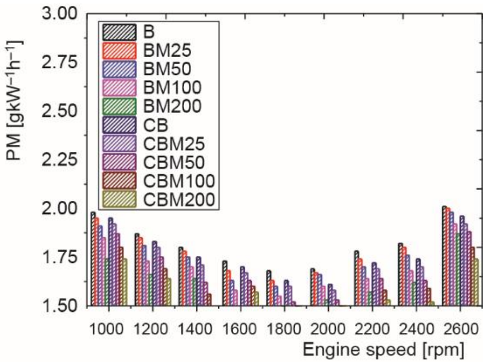

Figure 7. Change of PM emission value

The heating value of the fuel mixtures increased with the addition of nanoparticles, and at the same time, NO_x emissions completed the trend of increasing the combustion efficiency of the nanoparticle. In the coated engine, on the other hand, NO_x emission values continued to increase. This can be explained by the increase in the combustion end temperature in the cylinder. As we explained in the previous section, the exhaust gas temperature had increased. In this case, it is expected that NO_x emissions will increase. The highest NO_x emission value was measured as 6.55 g/kWh with the CBM200 fuel mixture in the coated engine. The highest increase rate was calculated as 10.7% with the use of the CBM200 fuel mixture in the coated engine.

In fig. 7, the variation of PM emission value in coated and uncoated engines according to engine speed and fuel type is given. The PM is formed because of the condensation of heavy HC in the gas phase with excessive temperature in the extremely rich air/fuel mixture regions, the inability of carbon atoms to react in the absence of oxygen, and the accumulation of partially burned fuel and oil molecules. The PM emissions are high at low engine speeds (1000 rpm and 1200 rpm), decrease as the engine speed approaches the maximum engine torque speed, and increase with the right engine speed (2000 rpm, 2200 rpm, and 2400 rpm). At low and high engine speeds, the amount of fuel taken into the cylinder worsened the air/fuel ratio, causing an increase in PM emissions. With the addition of nanoparticles to biodiesel fuel, PM emissions decreased at all fuel mixing ratios and engine speeds. This can be explained by the fact that the addition of nanoparticles increases combustion efficiency. With the use of fuel mixtures in the coated engine, PM emissions continued to show a decreasing trend at all engine speeds. This can be explained by the increase in the end-of-combustion temperature and the better combustion of the fuels taken into the cylinder. The highest PM was measured at 2600 rpm with the B fuel mixture as 2.01 g/kWh, while the lowest PM was 1.42 g/kWh at 1800 rpm with the use of the CBM200 fuel mixture in the coated engine. The highest reduction amount compared to pure biodiesel fuel was obtained with the use of CBM200 fuel mixture at an engine speed of 1800 rpm with 15.9%.

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